THE SUNYAEV-ZELDOVICH EFFECT AT 1 AND 2 MM TOWARDS ROSAT CLUSTERS

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Abstract

An observing campaign was devoted to the search for the Sunyaev-Zeldovich (S-Z) effect towards X-ray ROSAT Clusters in the millimetric spectral domain. A double channel (1.2 and 2 *mm*) photometer was installed at the focus of the 15m Swedish ESO Submillimeter Telescope (SEST) in Chile in september 1994 and 1995 and observations of the targets S1077, A2744, S295 and RXJ0658-5557 were gathered. Detections were found for A2744 at 1 *mm* and in both channels (at 1.2 and 2 *mm*) towards RXJ0658-5557. For the first time there is evidence for the S-Z enhancement and both the latter and the decrement were detected on the same source. We discuss astrophysical and systematic effects which could give origin to these signals.

1 Introduction

The S-Z effect is one of the major sources of secondary anisotropies of the Cosmic Microwave Background (CMB), arising from (inverse) Compton scattering of the microwave photons by hot electrons in clusters of galaxies. This effect generates a peculiar signal with a decrement at wavelengths longer than $1.4mm$ and an enhancement at shorter ones relative to the CMB planckian value.

The original computation by Sunyaev and Zeldovich [1−3] of the the net transfer of energy from the hot e$^-$ to the microwave photons predicts a signal for the relative temperature change:

$$(\frac{\Delta T}{T})_{therm} = \; y \; (x \; \frac{e^x+1}{e^x-1} - 4). \tag{1}$$

where T is the CMB temperature, $x = h\nu/kT$ and $y = \int(kT_e/mc^2)\ n_e\sigma_T d\ell$ is the comptonization parameter, n_e, T_e being the electron density and temperature. Equation 1 is an approximated solution of the full kinetic equation for the change of the photon distribution due to scattering. A more accurate solution gives rise to corrections which are not negligible at high frequencies [4].

If the cluster has a peculiar velocity relative to the frame where the CMB is isotropic an additional *kinematic* effect should be measured. The motion of the gas cloud will induce a Doppler change whose relative amplitude, $(\frac{\Delta T}{T})_{kin}$, does not depend on the frequency but only on the peculiar velocity, v_r, and cloud optical depth for Thomson scattering, τ,: $(\frac{\Delta T}{T})_{kin} = -\frac{v_r}{c}\tau$ (where the minus sign refers to a cluster receding from the observer). Since both effects are very small the net relative temperature change is the sum of the two: $(\frac{\Delta T}{T})_{SZ} = (\frac{\Delta T}{T})_{therm} + (\frac{\Delta T}{T})_{kin}$.

There is considerable interest in the detection of this effect also because of its potential in determining the distance of clusters, their peculiar velocities and in studying the intracluster medium [1−3]. Most of the observations carried out so far (e.g. [5]) were taken in the Rayleigh - Jeans (R-J) part of the spectrum, where the scattering leads to an intensity decrement. The more recent radio observations agree in finding this decrement at centimeter wavelengths towards A2218, A665, 0016+16, A773, A401, A478, A2142, A2256 [6−9] and Coma [10] and at 2.2mm towards A2163 ([11] and Lange, these proceedings).

Measurements near the planckian peak and on the Wien side have several advantages: (a) the intensity enhancement relative to the planckian value is larger than the magnitude of the R-J decrement; (b) the simultaneous detection of the enhancement (positive) and decrement (negative) on the same cluster provides an unambiguous signature of their presence and minimize systematic errors and spurious signals; (c) sources in the cluster are expected to give a negligible contribution at high frequency, while radio observations are plagued by the possible radio emission from sources within the clusters; (d) because of the large bandwidth the sensitivity of bolometer systems is excellent.

2 The Instrument

A double channel photometer was built and devoted to the search for the enhancement and decrement of the S-Z effect. The system works, in fact, simultaneously at 1.2 mm and 2 mm using two bolometers cooled at 0.3 K by means of a ^{3}He refrigerator. The 2mm band includes the peak brightness of the decrement in the S-Z thermal effect, while the 1.2mm bandwidth is a compromise between the maximum value of the enhancement in the S-Z and the atmospheric transmission. The collecting optics, cooled at 0.3 K, define a field of view in the sky of $44''$ at both frequencies. The beam separation in the sky was limited by the antenna chopping system and was set to the maximum chopping amplitude: $135''$.
This photometer was built to feed the O.A.S.I. (Osservatorio Antartico Submillimetrico Infrarosso) telescope installed at the Italian base in Antarctica [12] and was adapted to the focus of the SEST and its performance was tested during an observing run in September 1994. Details of the instrument can be found in [13].

Responsivities, beam shapes and widths were measured with planets and the main figures measured at the focus are listed in table 1. Sensitivities are also given in terms of relative change of the thermodynamic temperatures in one second integration time.

Table 1. Performances of the photometer at focus

λ_c (μm)	$\Delta\lambda$ (μm)	FWHM ($'$)	noise (nV/$\sqrt{Hz}$)	Responsivities ($\mu V/K$)	N.E.T. (mK/s)	$(\frac{\Delta T}{T})_{therm}$ (1s)
1200	360	44	45	3.0	7.5	0.010
2000	580	46	31	1.4	10.7	0.007

3 Observations

The targets were selected because of their high X-ray luminosity in the ROSAT band (0.5÷2.4 keV) $\sim 2 - 5\ 10^{45}$ erg/s and because of their high redshift (0.3-0.42). The apparent size of the core radius, being small, well matches the beam size: for a core radius of 250÷400 kpc in standard cosmologies the apparent size is $(40\div60)''$. However, a chop throw of $135''$ means that at the reference beam position the ratio between the electron density, $n_e(\theta = 135'')$, to its central value, $n_e(\theta = 0)$, is 0.25 - 0.35, i.e. 20 - 30 % of the signal could be lost because of the limited chop throw.

The present paper deals with observations of A2744 and RXJ0658-5557 carried out in four different nights during september 1-5 1995. A total integration time of 10800s and 12400s were spent on A2744 and RXJ0658-5557 respectively, and the same integration time was spent on a blank sky located 15m ahead in right ascension with respect to the source position. During the observations the sky opacity was very low ($\tau_{1mm} < 0.1$ with an average value of $< \tau_{1mm} >= 0.07$, $\tau_{2mm} < 0.05$ with an average value of $< \tau_{2mm} >= 0.03$) and the sky emission very stable thus producing a very low sky-noise.
In order to get rid of the major sources of noise in this kind of experiment, fluctuations in the atmospheric emission and systematics from the antenna, the observing strategy makes use of two combined procedures: the common three-beam technique, beam-switching + nodding, which gets rid of the linear spatial and temporal variations in the atmospheric emission, and the observations of blank sky regions located at right ascension position of 15m ahead with respect to the location of the source. This latter implies that for each 10m integration ON the source (10m integration + overheads give a total tracking time of 15m) a similar integration is performed on blank sky. The comparison between the two signals is a measurement of the systematics introduced by the antenna. In fact, the instrument tracks the same sky position twice with respect to the local environment, once ON the source and the other on the blank sky (position OFF). The choice of 600s of integration ON and OFF the source is a compromise between the minimization of the time wasted on overheads and the need of minimizing the atmospheric variations between one observation and the other.

The data analysis procedure is described in detail elsewhere[14]. Briefly, data on each sky position (on the source and on the blank sky) consist of differential measurements of the antenna temperature, ΔT_{ant}, with integration chunks lasting 3 x 200s. 200s data are averaged and a variance is assigned for each of this *"scan"*.
Weighted means are computed over the 600s integration when the antenna tracked the source (hereafter called ΔT_{ON}) and when the antenna tracked the blank sky (hereafter called ΔT_{OFF}). Cluster signals are then estimated from the subtraction: $\Delta T_{SZ} = \Delta T_{ON} - \Delta T_{OFF}$ and the quadratic sum of the two standard deviations are used to estimate errors: $\sigma^2_{SZ} = \sigma^2_{ON} + \sigma^2_{OFF}$.
Figure 1 (a,b,c,d) shows the values ON (filled squares) and OFF (empty squares) of the antenna

temperatures of the two clusters and for both channels. The solid lines represent the maximum likelihood estimates of the ΔT_{SZ}, while the dotted lines correspond to the 70% confidence range. This was found by computing the values of the signal where the likelihood drops by a factor of 1.71 from its maximum. From the figure one can infer that a 3σ detection can be claimed in both channels for RXJ0658-5557: $\Delta T_{1mm} = 0.3$ mK, $\Delta T_{2mm} = -0.46$ mK, while a signal of $\Delta T_{1mm} = 0.18$ mK, is present only at $1mm$ for A2744.

To check whether these detections were spurious additional measurements were carried out to test the behaviour of (a) the photometer + the electronic chain and (b) the antenna systematics. The *same* observing strategy (on the source and on the blank sky) was applied in two cases: (a) blocking the photometer entrance window and (b) following an empty sky region for integration times comparable with those used for the observations of the sources.

No signals are detected at a level of 0.1 mK (3σ) so that we believe that the adopted observing strategy gets rid of most of the unknown systematics (however one must note that if during the observation of the sources the antenna, because of a loss of synchronization, did not track *precisely* the same paths relative to the local environment, when looking at the source and at the blank sky some, very small spurious signals can survive).

4 Discussion

If the detected signals are due to clusters several questions are raised. We briefly discuss here only the case of RXJ0658-5557.

Let us assume that the decrement seen at $2mm$ is due to the SZ effect. From this value the *expected* $1mm$ signal for the thermal effect can be easily computed by convolving eq.1 with the beam shape, the optics transmission and the atmospheric spectrum. However, the difference with the observed value is larger than a factor of 2 and this can be explained either with a large peculiar velocity of the cluster, of the order of -1000 km/s, or with a source contaminating mainly the $1mm$ channel. To our knowledge there is no determination of the peculiar velocity from optical data and we are not able to verify the first hypothesis. The latter can be checked in several ways.

(1) No sources in the IRAS Faint Source Catalogue or in the 5GHz NRAO survey are present at the position of the main beam and/or of the reference beams.

(2) If we scale the $60\mu m$ IRAS flux limit of 240 mJy at $1.2mm$ by using the average flux of nearby spirals [15], we find that a normal spiral would give rise to a signal not larger than 0.02 mK in antenna temperature.

(3) If we assume a contribution of many unresolved sources fluctuating in the beam and take the estimation made by Franceschini et al. ([16]), the expected signal will be not larger than 0.02 mK.

(4) Irregular emission from the Galactic cirrus can also give origin to a signal at these wavelengths. If we take the estimation by Gautier et al. ([17]) and extrapolate the $100\mu m$ flux at 1.2 mm using the average Galactic spectrum a maximum signal of 0.02 mK is found.

(5) If part of the signal is due to CMB anisotropies at these scales, it will be hard to disentangle them from the S-Z kinematic effect since this latter has a spectrum identical to that of the anisotropies (see e.g. [18]).

We conclude that it is very likely that part of the signal at 1.2 mm is due to one or more sources but at present it is hard to identify it. This point however deserves further investigations and it will be the goal of future research.

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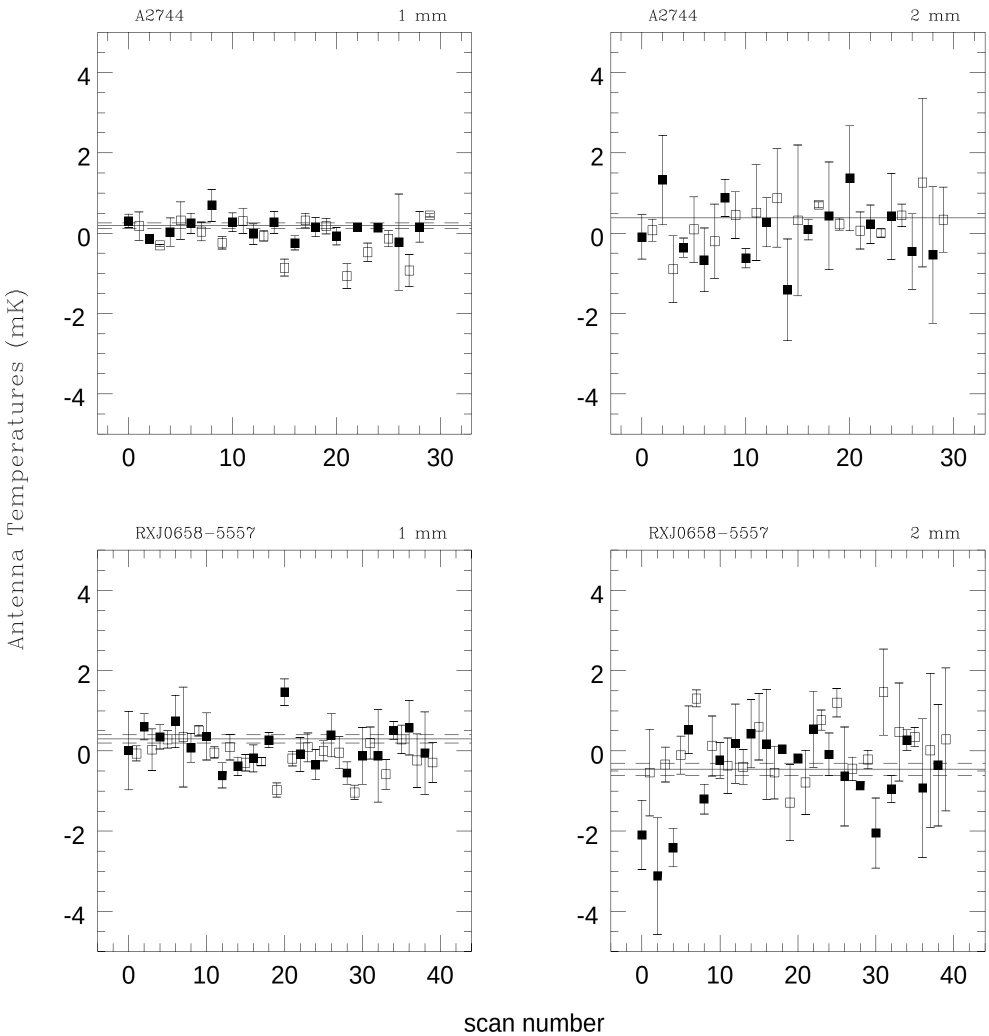

Figure 1: Differential antenna temperatures at 1 and 2 *mm* for A2744 and RXJ0658-5557. Filled squares refer to data ON the source, while empty squares to blank sky regions located 15m ahead in R.A. with respect to the source position. The cluster signals are estimated by subtracting $\Delta T_{SZ} = \Delta T_{ON} - \Delta T_{OFF}$. The maximum likelihood values of these differences is shown as a solid line while the dashed lines correspond to 70% confidence interval. For the 2 *mm* signal of A2744 only the 3σ upper limit is reported.